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EVOLUTIONARY SPACE STATION FLUIDS MANAGEMENT

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INTRODUCTION

Current NASA planning activities foresee the Space Station as an orbiting facility for supporting the human exploration and mission-to-planet Earth initiatives, staging and servicing commercial and scientific satellites, and conducting a variety of on-board scientific and technology development activities. These activities will involve the accommodation and management of a diverse variety of propellants and other fluids at the Space Station. The impact on and requirements for accommodations of these missions by the evolutionary Space Station infrastructure must be understood, and the proper "hooks and scars" incorporated into the baseline design. A FY88 study, by General Dynamics Space Systems Corporation, has catalogued the projected R&D fluid needs and FY88 Office of Exploration (Code Z) case studies propellant requirements, examined preliminary fluid management concepts, and suggested means of accommodation and impacts to the Space Station. In FY89, an activity will be initiated to examine, more specifically and in-depth, the fluid management aspects of the on-orbit storage and transfer of large quantities of cryogenic propellants using the Space Station as a base of operations for these activities, required Space Station accommodations, and impacts to the Space Station infrastructure.

INTRODUCTION

- SPACE STATION WILL SERVE AS A STAGING NODE FOR THE MANNED EXPLORATION INITIATIVES; CONSEQUENT HANDLING IMPLICATION OF LARGE QUANTITIES OF CRYOGENIC PROPELLANTS
- ADDITIONAL/ALTERNATIVE SPACE STATION UTILIZATION IMPOSES OTHER FLUIDS REQUIREMENTS
- IMPACT ON AND REQUIREMENTS FOR ACCOMMODATION OF THESE FLUIDS BY THE EVOLUTIONARY SPACE STATION INFRASTRUCTURE MUST BE DETERMINED
- OPTIMUM FLUID MANAGEMENT STRATEGIES TO MINIMIZE ADVERSE IMPACTS TO THE SPACE STATION AND PRODUCTIVITY MUST BE DETERMINED
- ANTICIPATE POTENTIAL SPACE STATION UTILIZATION AND FLUIDS NEEDS
  - IDENTIFY AND INCORPORATE "HOOKS AND SCARS" IN BASELINE PROGRAM
  - IDENTIFY NECESSARY TECHNOLOGIES

OBJECTIVES

The objectives of this effort were to identify the types and quantities of fluids expected to be associated with Space Station Freedom during its evolutionary phase (growth beyond Phase I), the associated fluid management issues and requirements, concepts for accommodating these fluids at the Space Station, requirements imposed on the Space Station infrastructure (systems, subsystems, operations) and, in particular, the necessary scarring to be included in the baseline Space Station design so as to not preclude the potential future fluid management needs.

OBJECTIVES OF 1989 EFFORT

- CONDUCT AN INVENTORY OF ALL FLUIDS EXPECTED TO BE ASSOCIATED WITH THE SPACE STATION DURING ITS INITIAL AND EVOLUTIONARY PHASES
- IDENTIFY FLUID MANAGEMENT REQUIREMENTS SUCH AS STORAGE, SUPPLY, TRANSFER, HANDLING, THERMAL, AND SAFETY ISSUES
- DEVELOP OPTIMAL FLUIDS MANAGEMENT STRATEGIES AND CONCEPTS FOR FLUIDS ACCOMMODATION THAT MINIMIZE IMPACTS TO SPACE STATION SYSTEMS AND ITS OPERATIONS
- IDENTIFY "HOOKS AND SCARS" TO BE INCORPORATED IN THE BASELINE DESIGN AND NEEDED FUTURE TECHNOLOGIES

FLUID CATEGORIES

Five categories of potential fluids usage at the space station were identified. These were:

1. Research payloads including both attached to the space station and free flying. Fluids here include cryogenic helium for scientific instruments nitrogen for attitude control, hydrazine for propulsion, and rare gases for other sensors and instruments.

2. Propellants for unmanned planetary missions potentially utilizing the space station.

3. Space Transfer Vehicle (earth orbital applications) propellant requirements. The propellants are cryogenic hydrogen and oxygen for a space transfer vehicle (STV) to position payloads in geostationary orbit and other earth orbits.

4. Orbital Maneuvering Vehicle (OMV) propellant requirements. The OMV deploys, retrieves, and services payloads and utilizes, nitrogen, hydrazine (as a monopropellant), and hydrazine/nitrogen tetroxide (bi-propellant) for propellants.

5. Cryogenic hydrogen and oxygen and other fluids for the human exploration initiative.

FLUID CATEGORIES

- RESEARCH AND DEVELOPMENT FLUIDS
- PLANETARY INITIATIVES PROPELLANT
- SPACE TRANSFER VEHICLE (STV) PROPELLANT
- ORBITAL MANEUVERING VEHICLE (OMV) PROPELLANT
- CODE Z MISSIONS PROPELLANT

U.S. ATTACHED AND FREE-FLYING PAYLOADS

The research payloads for which the fluids requirements were determined consist of attached and free-flying payloads. The research facility names and acronyms, which are used on the next chart, are presented here.

U.S. ATTACHED AND FREE-FLYING PAYLOADS (R&D FLUIDS)

ATTACHED

1. ASTROMAG* - ASTROPHYSICS MAGNET FACILITY
2. DXS* - DIFFUSE X-RAY SPECTROMETER
3. LAMAR* - LARGE AREA MODULAR ARRAY
4. STO/SIG* - SOLAR TERRESTRIAL OBSERVATORY/SOLAR INSTRUMENT GROUP
5. STO/PIG* - SOLAR TERRESTRIAL OBSERVATORY/PLASMA INSTRUMENT GROUP

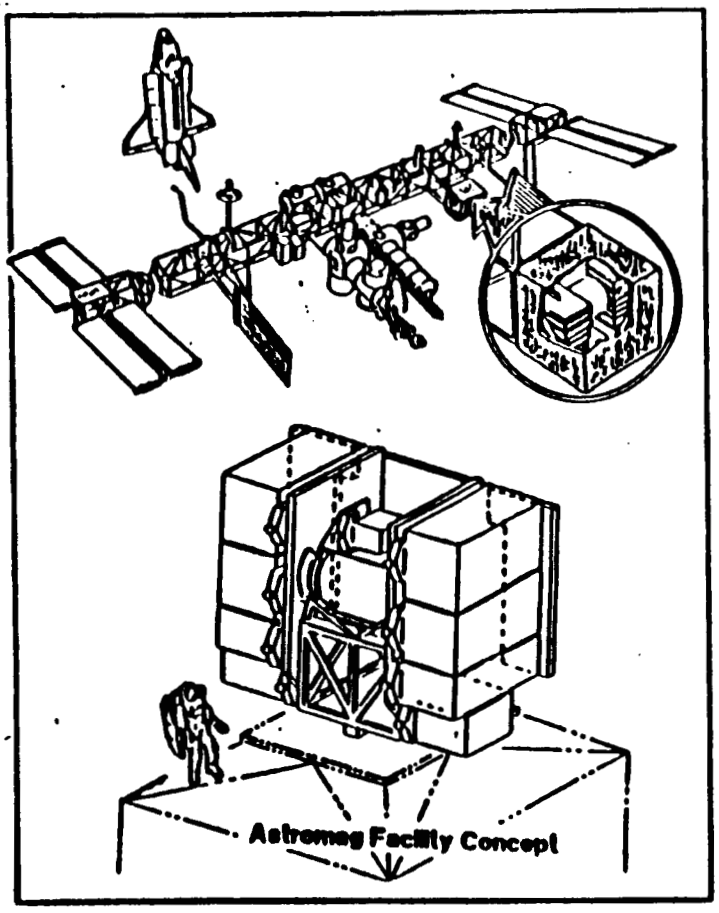
FREE FLYERS

6. STO/SS - SOLAR TERRESTRIAL/SPACE STATION ATTACHED
7. ASAF - ADVANCED X-RAY ASTROPHYSICS FACILITY
8. GRO - GAMMA RAY OBSERVATORY
9. LDR - LARGE DEPLOYABLE REFLECTOR
10. SBAR - SPACE BASED ANTENNA RANGE
11. SIRTF - SPACE INFRARED TELESCOPE FACILITY
12. 3S - SPACE STATION SPARTAN
13. STO/POP - SOLAR TERRESTRIAL OBSERVATORY/POLAR ORBITING PLATFORM
14. XGP - EXPERIMENTAL GEO PLATFORM

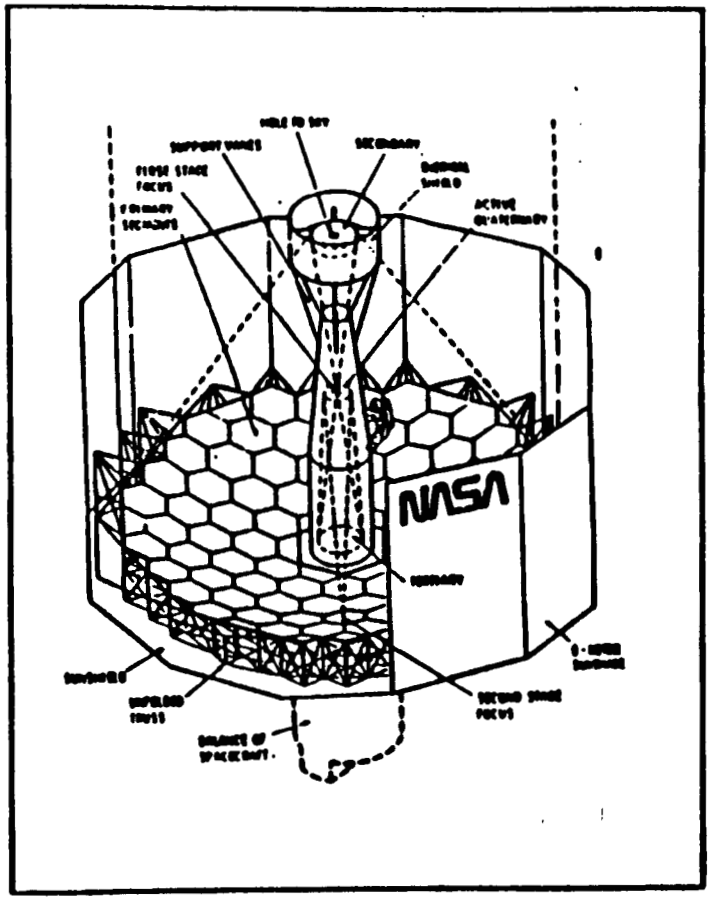
EXAMPLE SPACE STATION RESEARCH PAYLOADS

Two of the research facilities requring fluids replenishment are the Particle Astrophysics Magnet Facility (ASTROMAG), an attached payload, tne the Large Deployable Reflector (LDR), which is a free-flyer. The ASTROMAG requires superfluid helium replenishment and possibly rare gas mixtures. The LDR also requires superfluid helium.

EXAMPLE SPACE STATION RESEARCH PAYLOADS



Particle Astrophysics Magnet Facility (ASTROMAG)



Large Deployable Reflector (LDR)

U.S. RESEARCH PAYLOAD FLUID REQUIREMENTS COMPOSITION

The individual fluid types and amounts needed during each year to support the U.S. research payloads are graphically summarized on this chart. The international fluids needs, although not shown here, were estimated to be 30% of the U.S. requirements. The greatest demands are for hydrazine and helium, which comprise 49 and 37% of the fluid needs, respectively. The corresponding volume requirements of the fluids and a resupply schedule to meet the demand were also generated. At the time the data was generated, the space station was intended to be operational in 1996, hence the 1996 need date is shown on this and succeeding charts. The data would need to be adjusted for the current operational date.

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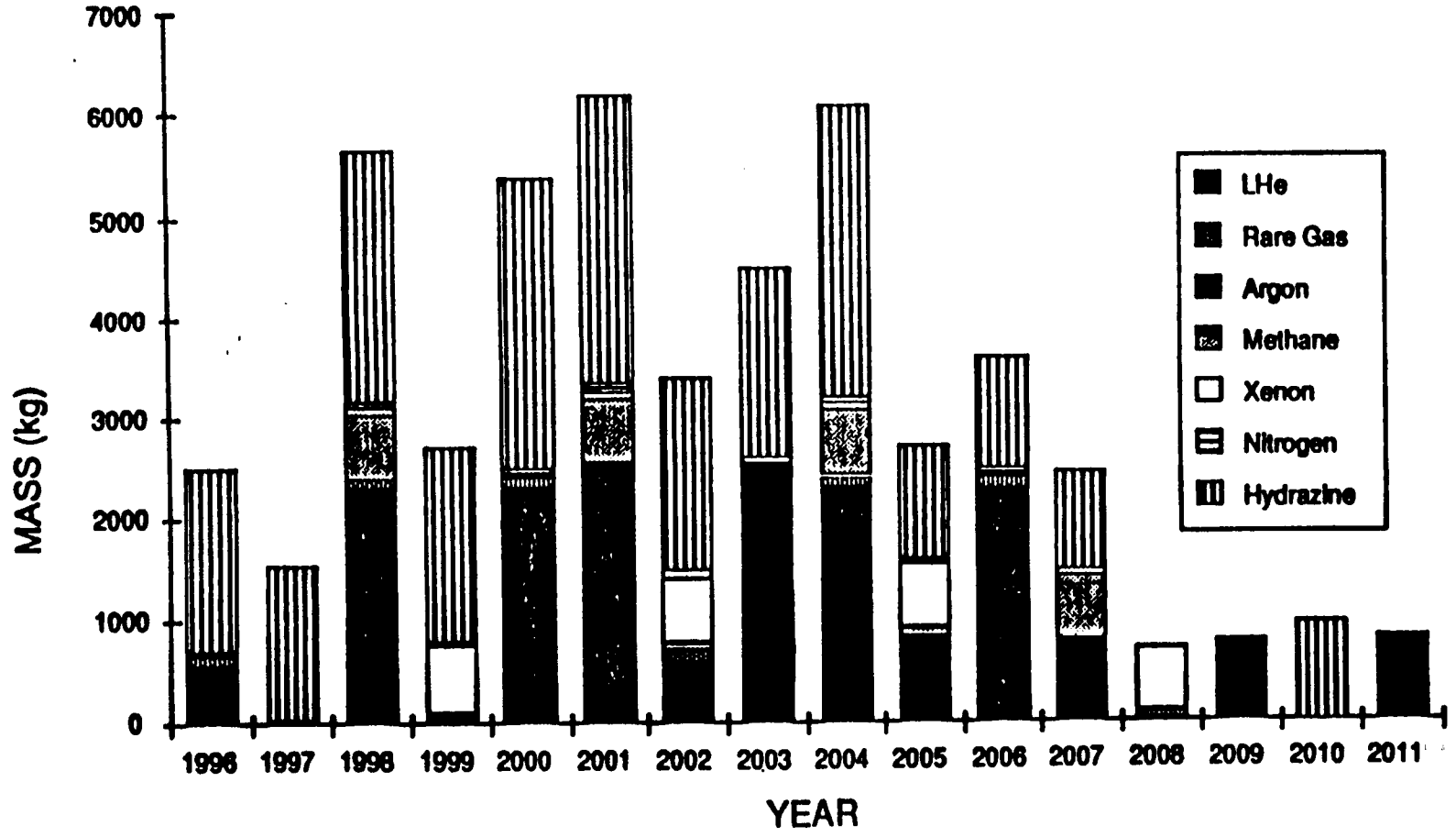
US EXPERIMENTAL PAYLOAD FLUID REQUIREMENTS COMPOSITION



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PLANETARY MISSION PROPELLANT REQUIREMENTS

This chart shows the propellant (hydrogen and oxygen) requirements for the unmanned planetary missions (the third fluids category) that might potentially utilize the space station as a fueling and launch node. The acronyms are defined as follows:

NEAR	Near-Earth Asteroid Rendezvous
CNSR	Comet Nucleus Sample Return
SF/P	Saturn Flyby/Probe
SO	Saturn Orbiter
MSP	Mars Surface Probe
CASR	Comet Atomized Sample Return
LL	Lunar Landers
MAO	Mars Aeronomy Orbiter
VAP	Venus Atmospheric Probe
MSR	Mars Sample Return

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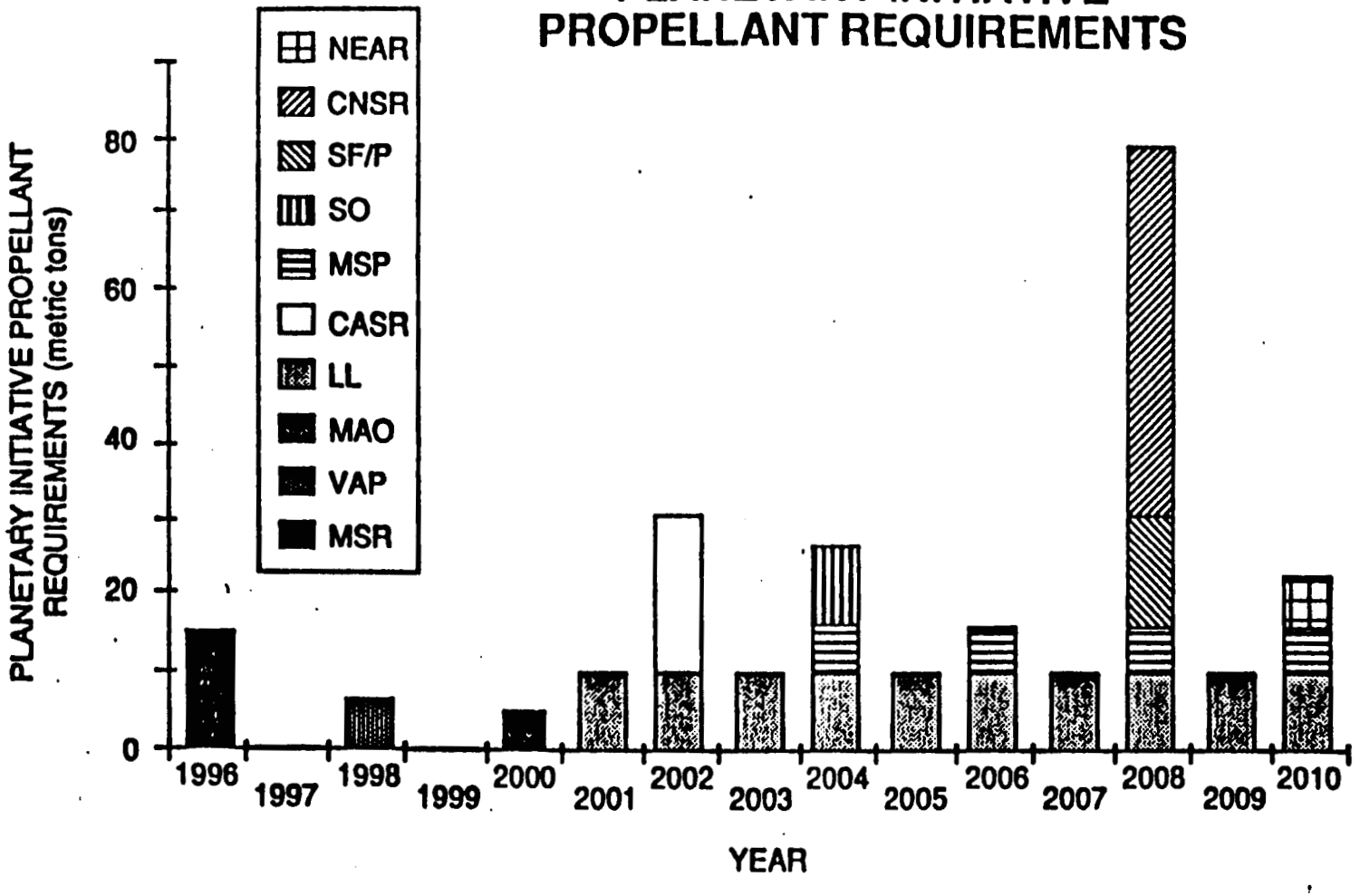
PLANETARY INITIATIVE PROPELLANT REQUIREMENTS



NOTE: This estimate of expendable STV propellant requirements comes from the "Space Station Transportation Interfaces", NASA, JSC, August 1988. It represents the augmented mission program recommended by the Solar System Exploration Committee of the NASA Advisory Council.

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SPACE TRANSFER VEHICLE PROPELLANT REQUIREMENTS

This chart shows the propellant requirements for the space transfer vehicle (STV). The STV will be used to retrieve and deliver payloads from the Space Station to higher energy orbits (e.g., geosynchronous). The propellant requirements for these missions are based upon NASA's Mission Model for the orbital transfer vehicle (OTV) (Revision 8) with all lunar and planetary missions removed. The STV reference configuration is the "synthesized" version. The propellants are liquid oxygen and hydrogen, burned at a 6:1 mass ratio. Although the STV model used in this study is larger than the current STV flight estimates, the addition of DOD missions and Mission-to-Planet-Earth geosynchronous fluid requirements will result in an increase in the STV propellant requirements.

Accounting for the Mission-to-Planet-Earth Polar Orbiting Platform (POP) servicing would require extra propellant storage at the Space Station. However, servicing from the Space Station is not currently planned because polar orbits are most efficiently accessed from the ground (minimum delta V and propellant requirements). Therefore, POP servicing from the Space Station was not considered in this study.

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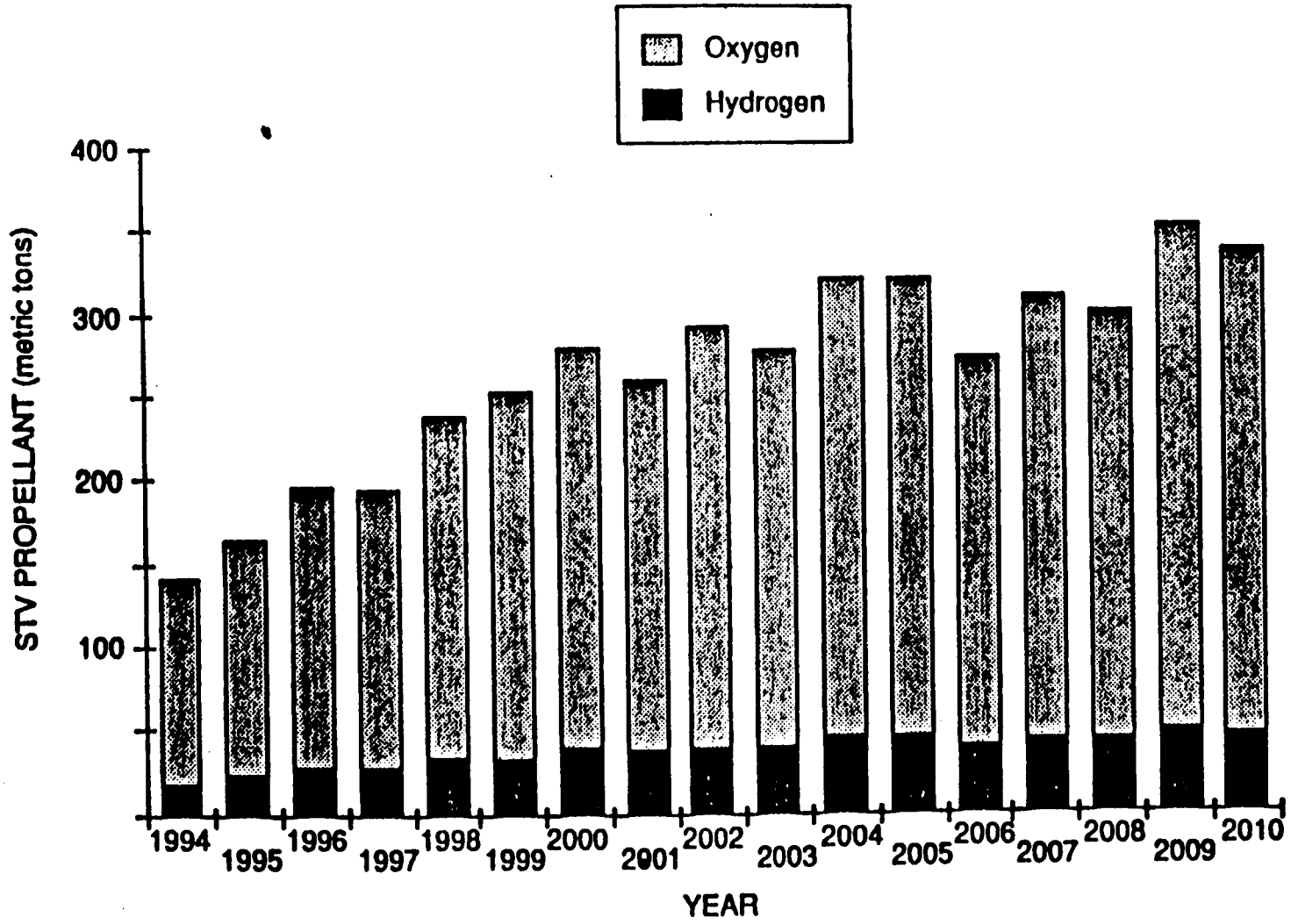
STV (NON-PLANETARY) PROPELLANT REQUIREMENTS



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ORBITAL MANEUVERING VEHICLE (OMV) PROPELLANT REQUIREMENTS

The fourth fluid category requirements, orbital maneuvering vehicle propellants, are shown here. Even though the OMV is currently designed to be serviced from the Shuttle, basing an OMV at the Space Station is practical, efficient, and "assumed" by a number of studies to exist. Therefore, a Space Station-based OMV concept was assumed for the purposes of this study. The OMV requires hydrazine, bi-prop, and nitrogen. Free-flying experiments also require hydrazine, which also makes hydrazine storage at the SS desirable. The chart shows the amount of OMV propellants required to support the flights identified. Although the number of flights do not extend beyond 2004 and are probably fewer than would be realized, they provide a basis for the study of the impact upon Space Station fluid management requirements. The number of OMV flights will probably be significantly greater when Station operations, logistics using expendable launch vehicles, satellite servicing and proximity transportation is accounted for. Data for the fluid requirements of these types of missions is not currently available.

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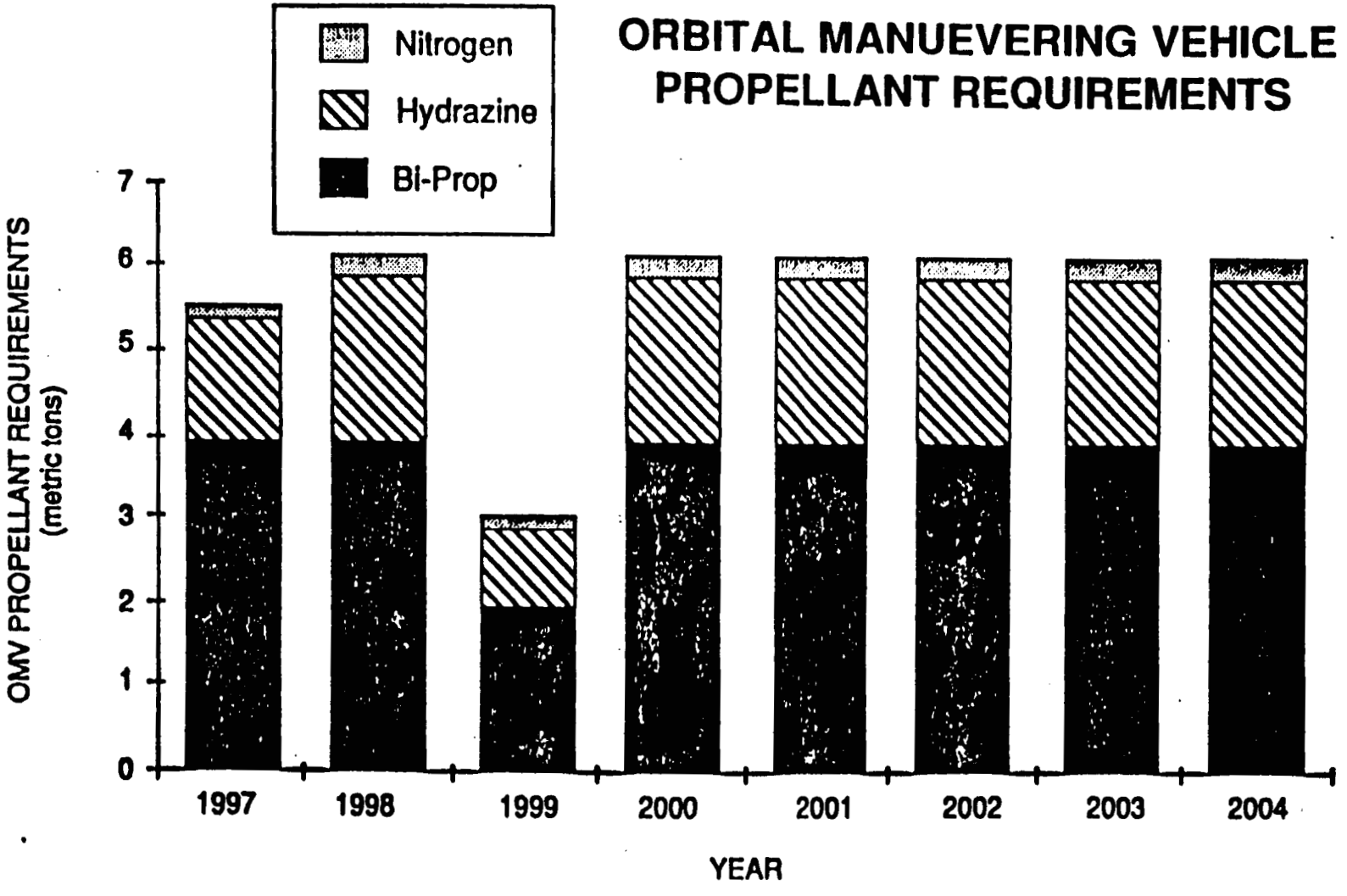
ORBITAL MANUEVERING VEHICLE PROPELLANT REQUIREMENTS



NOTE: This estimate of OMV propellant requirements comes from the "Space Station Transportation Interfaces", NASA, JSC, August 1988.

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CODE Z MISSION FLUID REQUIREMENTS

The Office of Exploration (Code Z) case studies are defined in the 1988 Code Z Annual Report (reference 2). This document identifies the propellant requirements for the Human Expedition to Phobos, Human Expeditions to Mars, Lunar Observatories and Lunar Outpost to Early Mars Evolution missions. The Space Station fluid support requirements are separated into four individual schedules, each one based upon a single Code Z missions, since it is very unlikely that two or more Code Z missions will be done concurrently.

The chart illustrates the relative propellant quantity and timephasing requirements of the individual Code Z missions. It is important to note that the propellant amounts for the individual missions within a given bar on the chart are not additive, but must be considered individually. Although some of the fluid requirements for the Code Z missions are needed at locations other than LEO (i.e., lunar vicinity), it is assumed that the fluids will "go through" the Space Station or a co-orbiting depot before reaching their final destination. It is clear from this comparison that Mars Expedition propellant requirements are the greatest of the Code Z mission propellant requirements.

Due to the large quantities involved, it is unlikely that any of the Code Z propellants will be stored at the Space Station (due to operations, safety, logistics, dynamics, and stationkeeping considerations), unless the primary purpose of the SS becomes that of a transportation node.

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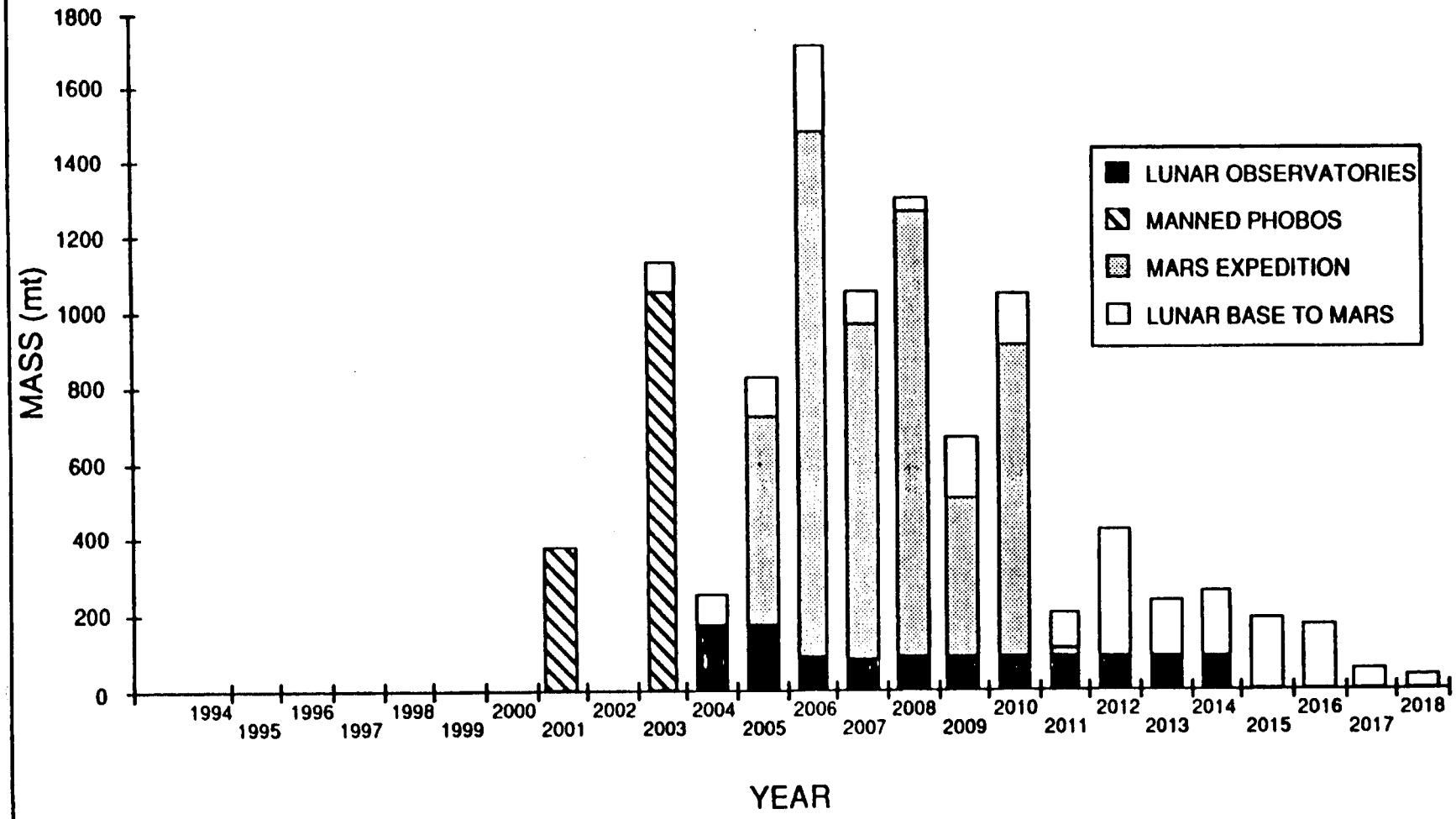
CODE Z MISSION FLUID REQUIREMENTS - LEO TO DESTINATION



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RESEARCH FLUIDS CARRIER CONCEPTS

The transport and storage of approximately 470,000 liters (150,000 kg) of R&D fluids (Space Station Users) is required to meet growth model requirements through the year 2010. Carrier design concepts were developed that are representative of the type of tankage which could satisfy the required range of fluid types/quantities, for a scenario which requires the bulk delivery and storage of fluids (which all of the considered options require in growth configurations).

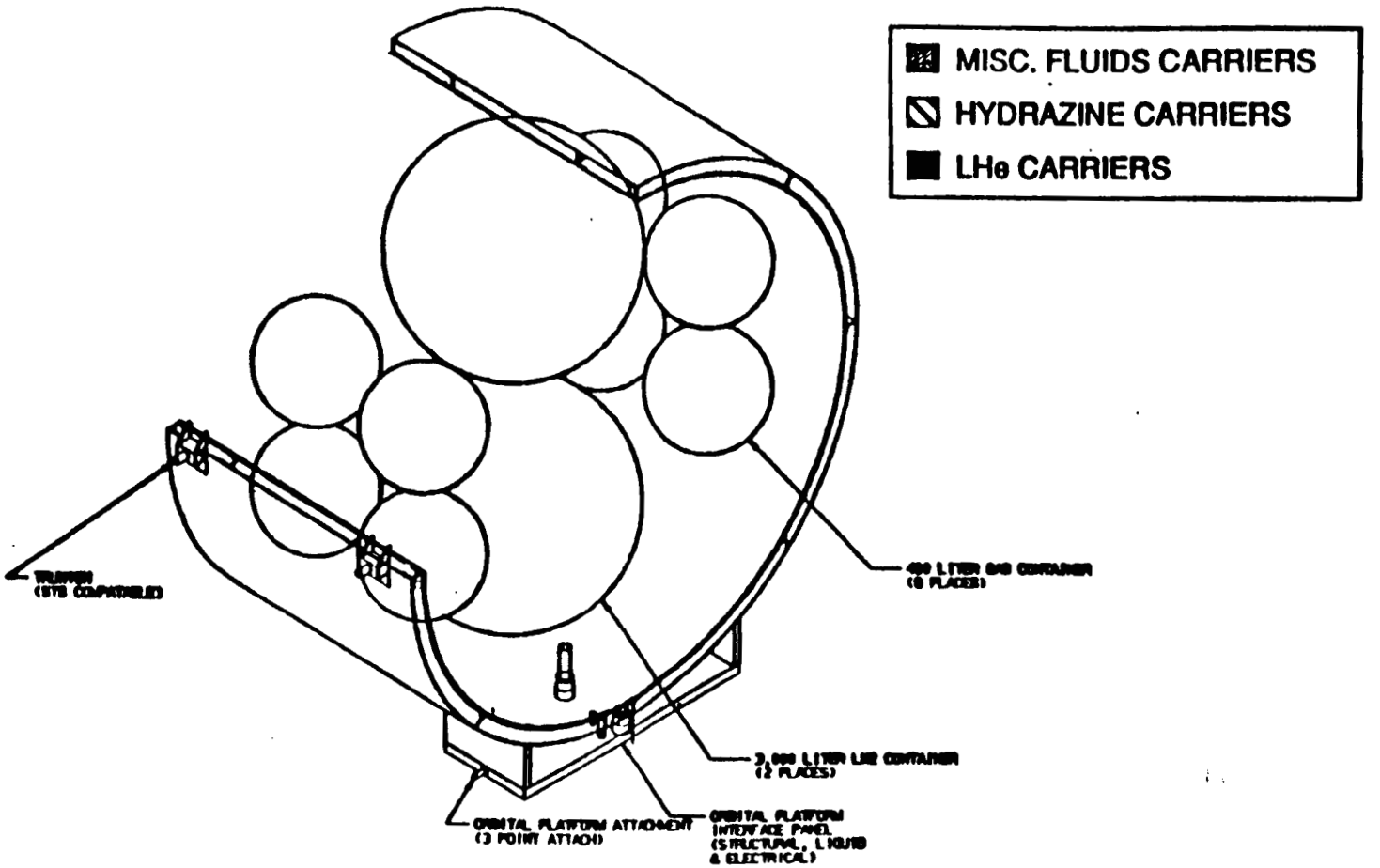
A modular conceptual design, such as the Miscellaneous Fluids Carrier shown on the chart, enables the delivered fluid quantity to be closely tailored to the requirements.

Nitrogen, argon, methane, xenon, and "rare" gas fluid requirements are satisfied by the Miscellaneous Fluids Carrier. This carrier consists of two liquid nitrogen spherical containers each with a capacity of 3,000 liters, and eight high pressure gas containers, each with a capacity of 400 liters.

The requirements for the gases (other than the nitrogen liquid) are so low that three foot diameter containers were selected for commonality and ease of handling and storage, and delivered volume of each is more than sufficient to provide the necessary fluids on orbit during a particular time period.

Since the masses and volumes of liquid helium and hydrazine far overshadow the amounts of the rest of the fluids combined, dedicated carrier concepts were formulated for those fluids, but are not shown here.

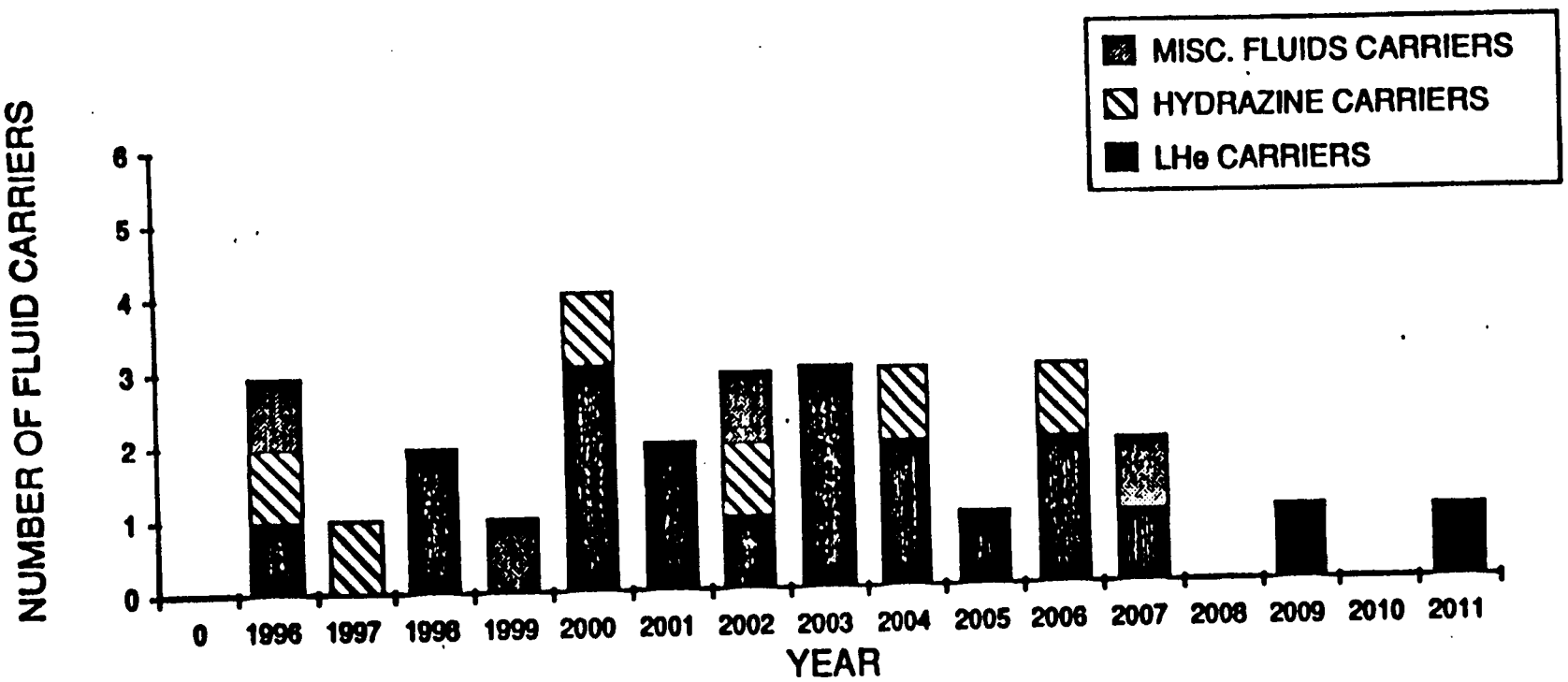
MISCELLANEOUS FLUIDS CARRIER (2 @ 3,000 LITERS & 8 @ 400 LITERS)


MISC. FLUIDS CARRIERS
HYDRAZINE CARRIERS
LHe CARRIERS
ORBITAL PLATFORM ATTACHMENT (3 POINT ATTACH)
ORBITAL PLATFORM INTERFACE PANEL (STRUCTURAL, LIQUID & ELECTRICAL)

U.S. AND INTERNATIONAL RESEARCH FLUID CARRIER REQUIREMENTS

A fluids replenishing schedule was developed to match the yearly demand, and then the number of fluids carriers needed per year was determined. Requirements analyses indicate a total launch requirement of a total of 30 fluid carriers through the year 2011, at a rate of 1 to 4 carriers per year. The chart shows the number of fluid carriers required per year for the three different fluid carrier types.

US & INTERNATIONAL EXPERIMENTAL FLUID CARRIER REQUIREMENTS



GROWTH SS WITH INTEGRATED FLUID MANAGEMENT SUBSYSTEMS

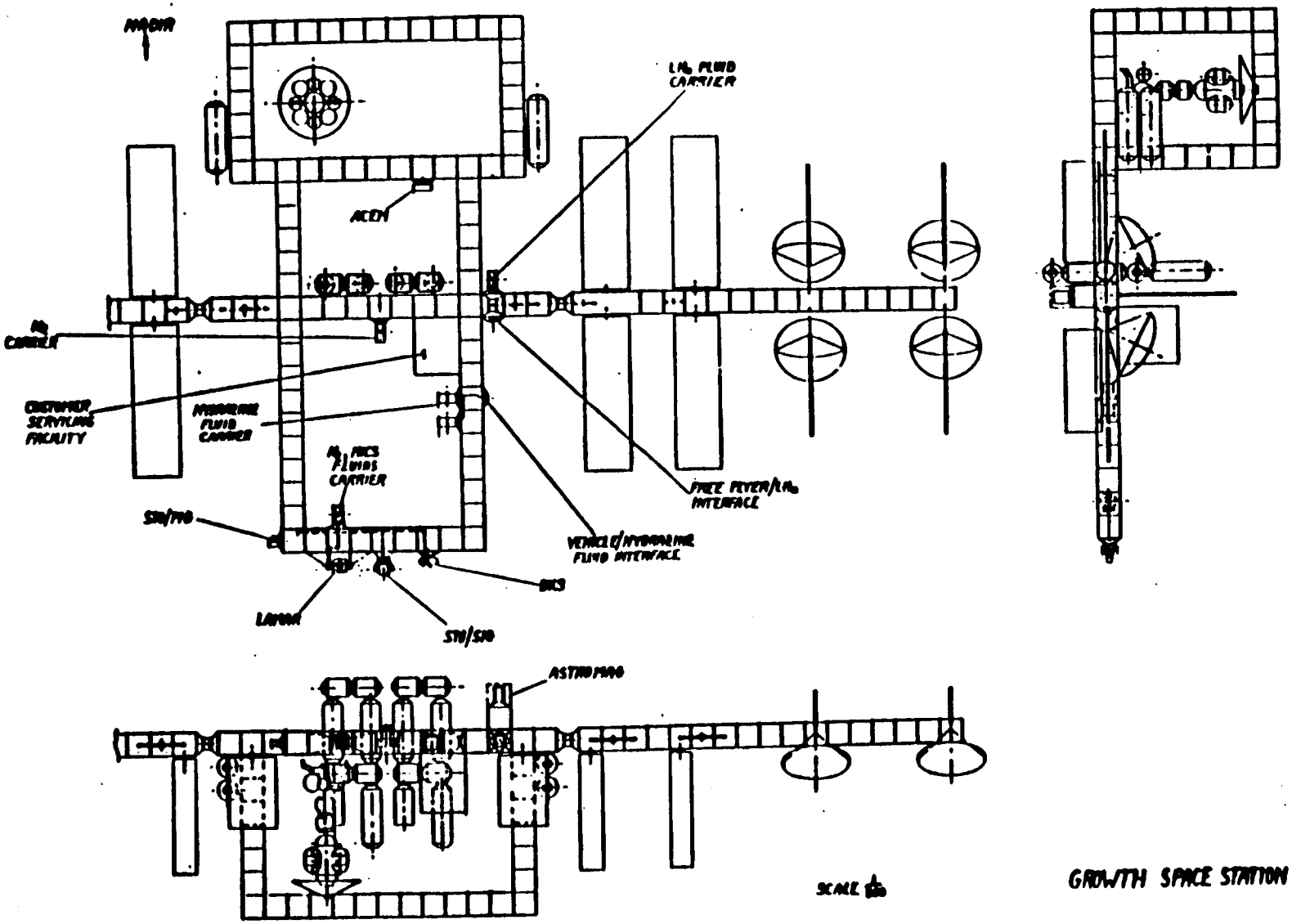
Attached Payloads

- LHe
  - Fluids carrier docked to LHe interface near ASTROMAG
  - Replenishment for each LHe user via "disconnectable" hard plumbed lines
- Gases
  - -Hard plumbed lines/Integrated Fluid Susbsystem when justifiable
- Nitrogen
  - Recharge ORUs through disconnect at INS
  - Nitrogen fluid carrier supplements INS capability
  - Experimental Payload connected to INS when justifiable

Free Flying Payloads

- LHe
  - Experiment/vehicle docked at SS, refilled via fluids interface near ASTROMAG
- Hydrazine
  - Experiment/vehicle docked at SS, replenished via fluids interface near CSF (interface hard plumbed to Hydrazine fluids carrier)
- Nitrogen
  - Experiment/vehicle refilled via fluids interface at CSF (interface hard plumbed to the INS)

GROWTH SS WITH INTEGRATED FLUID MANAGEMENT SUBSYSTEMS



CRYOGENIC PROPELLANT PROVISIONING APPROACHES

Large amounts of liquid oxygen and liquid hydrogen are required for the space transfer vehicle (STV) and human exploration initiatives. Concepts for managing these propellants include tank facilities attached to the space station and on co-orbiting platforms. General Dynamics, in an earlier contract for Marshall Space Flight Center (reference 3), developed a tankset concept for storing STV propellants. This tankset concept was used as the basic building block for the attached and co-orbiting propellant facilities shown on this and subsequent charts. This chart shows propellant tanks attached to the space station for propellant provisioning for the earth orbital and possibly lunar STV missions.

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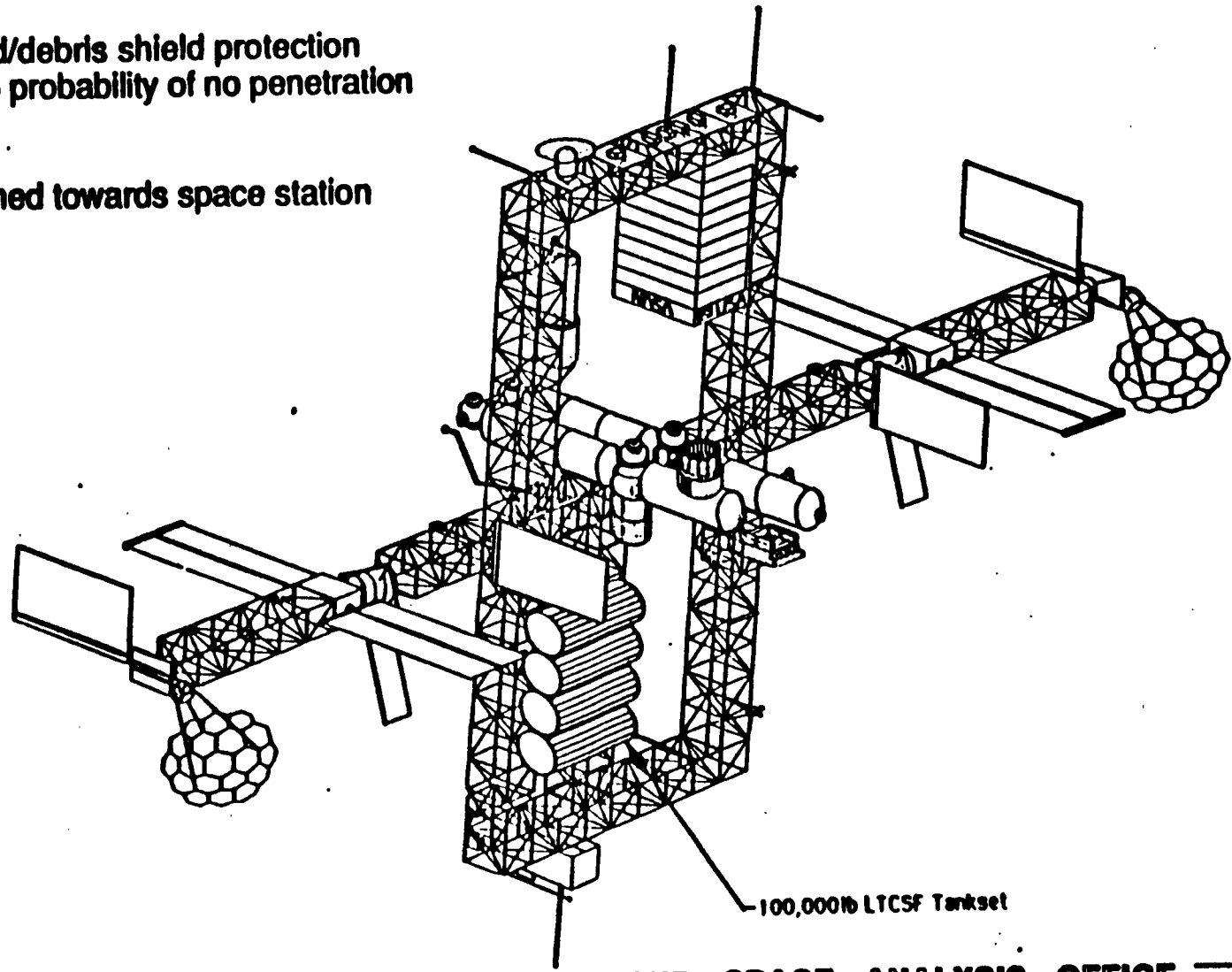
STV PROPELLANT ACCOMODATIONS AT SPACE STATION (4 TANKS @ 100KLB EACH)

- Micrometeoroid/debris shield protection to provide .995 probability of no penetration over 10 years
- Protection aligned towards space station velocity vector



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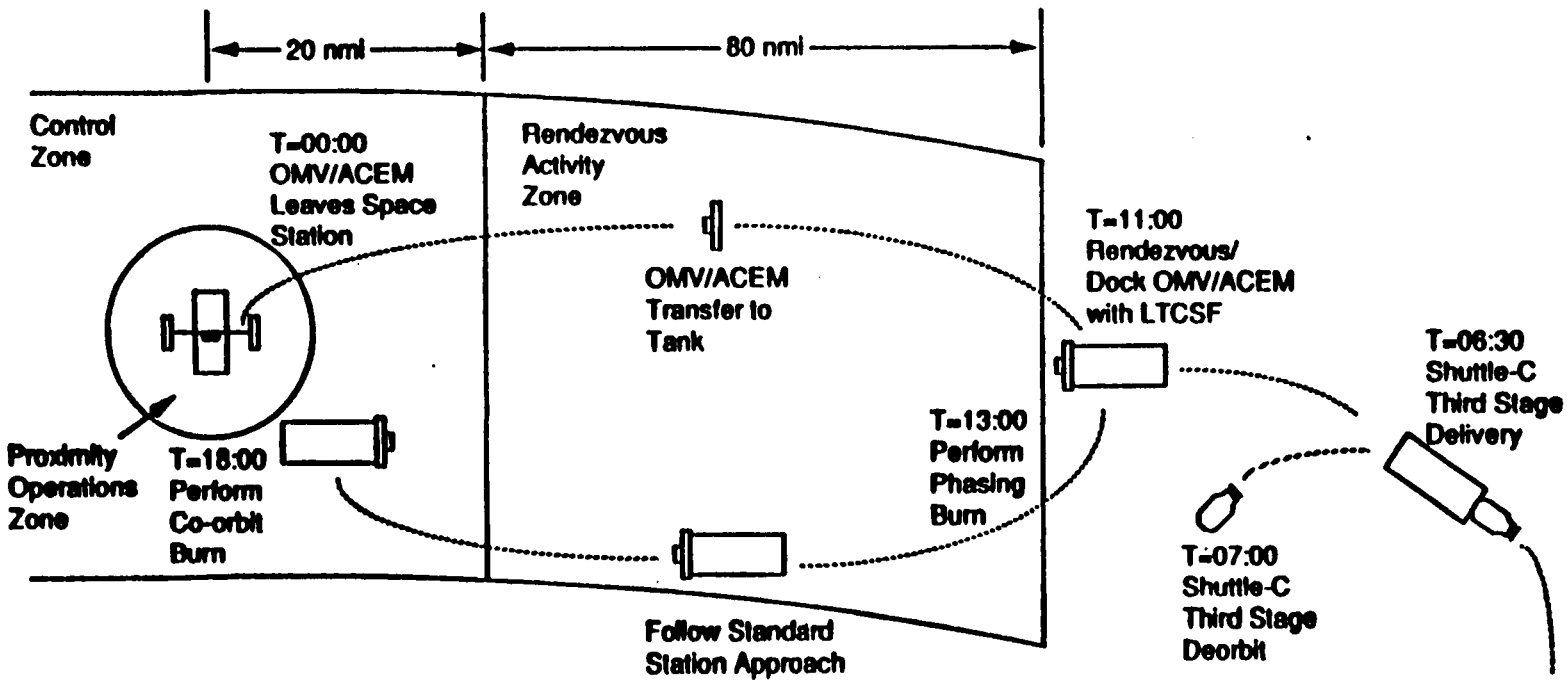
CRYOGENIC PROPELLANT TANK DELIVERY SCENARIO

A complete scenario of STV refueling and launch was formulated in order to examine the operations/accommodations required of the space station. The scenario included delivery of cryogenic propellants to the space station attached propellant facility, fueling the STV, and deploying and launching the STV.

The scenario for delivery of the tankset to the Station is depicted on this chart. This chart shows the delivery of the tank to the Station rendezvous zone by the Shuttle-Z third stage. The OMV/ACEM assembly travels from the Station, rendezvous and docks with the tankset, and stabilizes it. The OMV performs a burn with its main thrusters for about 20 minutes to initiate the phasing to bring the tank to the Station. Prior to arriving at the proximity zone, the tank is oriented and a burn is performed to co-orbit the tank with the Station. The ACEM cold gas thrusters perform the manuevers to bring the tank within reach of the MRMS.

These tanksets have a total wet (fully fueled) weight of 177k lb. and 245.5k lbs., respectively. These scenarios required that the OMV rendezvous with the tankset and ferry it to the Station. However, the OMV has been designed for a maximum payload weight of 75k lbs., assuming no maneuvering requirements. Bringing the tank to the Station requires positive attitude control throughout the transfer and the use of cold gas during the final approach for contamination reduction. A design solution has been proposed and is more fully described on a succeeding chart.

CRYOGENIC PROPELLANT TANK DELIVERY SCENARIO TO THE SPACE STATION



ACEM = Attitude Control Enhancement Module

OMV = Orbital Maneuvering Vehicle

NOTE: Times represent the beginning of the identified operation.

ATTITUDE CONTROL ENHANCEMENT MODULE (ACEM)

In order to increase the OMVs capability with minimum development costs, General Dynamics has developed an Attitude Control Enhancement Module (ACEM) design concept. The ACEM is attached to the front of (and controlled by) the OMV. To minimize the impact to the OMV, the ACEM will have its own batteries, signal processor, and thruster control hardware and software, but it will rely on the OMV for guidance, navigation, and control information. The OMV will relay the commands sent from the ground or Station to the ACEM.

The ACEM will have two deployable S-band omnidirectional antennas capable of extending beyond the diameter of the tanks to allow the OMV to communicate continuously with TDRSS and (or) the Space Station. Two thruster pods, each containing five 110 lb. thrust nitrogen thrusters, will also extend beyond the tank diameter. This will provide three axis control for the tank with sufficient force to allow yawing the tank 180° in about three minutes. The ACEM will carry a total of 1000 lbs. of nitrogen in eight 2.5 ft. tanks. These tanks will be refilled at the Station.

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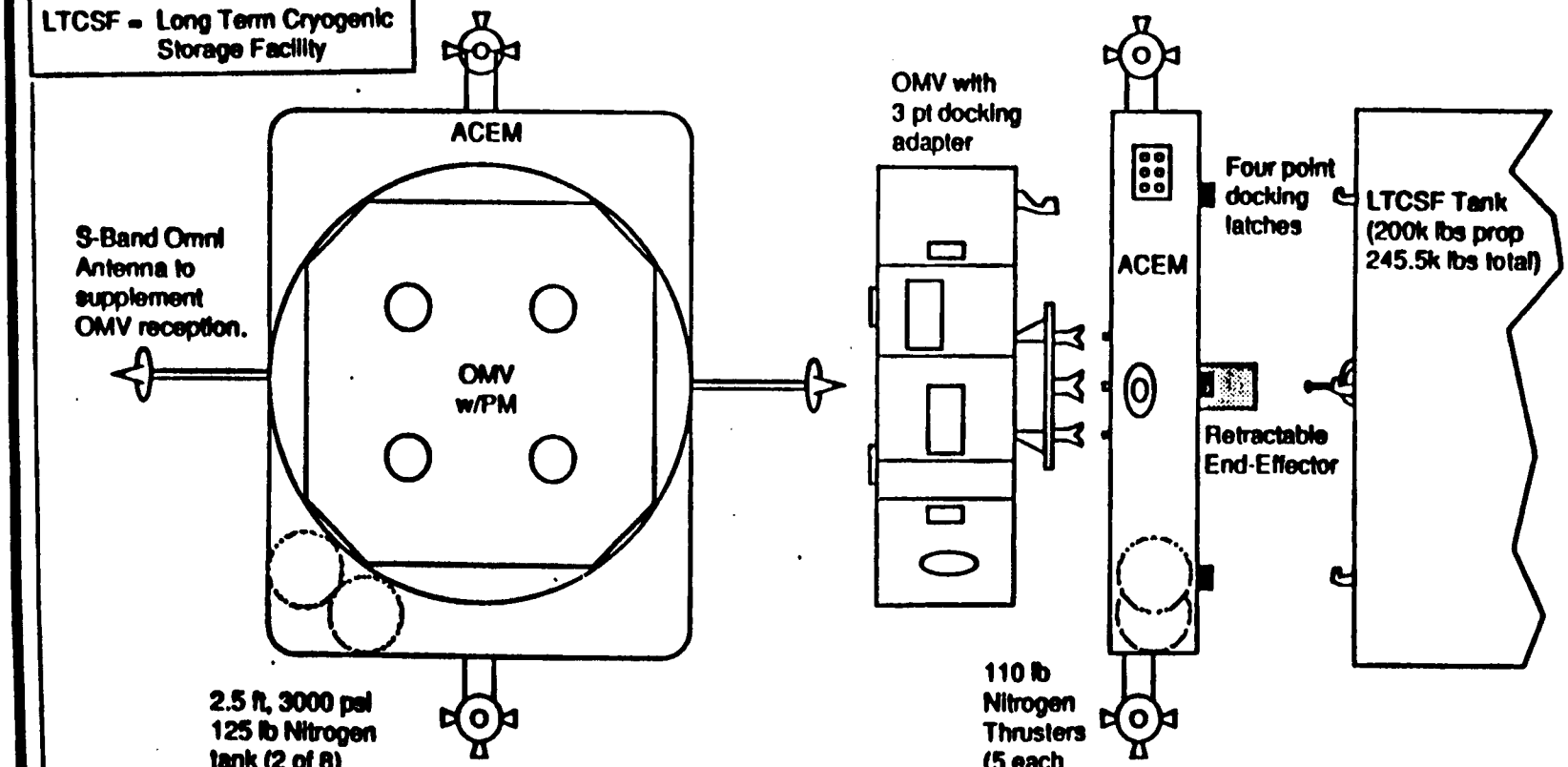
ATTITUDE CONTROL ENHANCEMENT MODULE (ACEM)

ACEM = Attitude Control Enhancement Module

OMV = Orbital Maneuvering Vehicle

PM = Propulsion Module

LTCSF = Long Term Cryogenic Storage Facility


ACEM
S-Band Omni Antenna to supplement OMV reception.
OMV w/PM
2.5 ft, 3000 psi 125 lb Nitrogen tank (2 of 8)
OMV with 3 pt docking adapter
ACEM
Four point docking latches
Retractable End-Effector
LTCSF Tank (200k lbs prop 245.5k lbs total)
110 lb Nitrogen Thrusters (5 each cluster)

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LUNAR OBSERVATORY MISSION PROPELLANT PROVISIONING

This chart shows an example of a co-orbiting platform for provisioning the propellants for the 1988 Code Z Case Study 3 "Lunar Observatory Mission."

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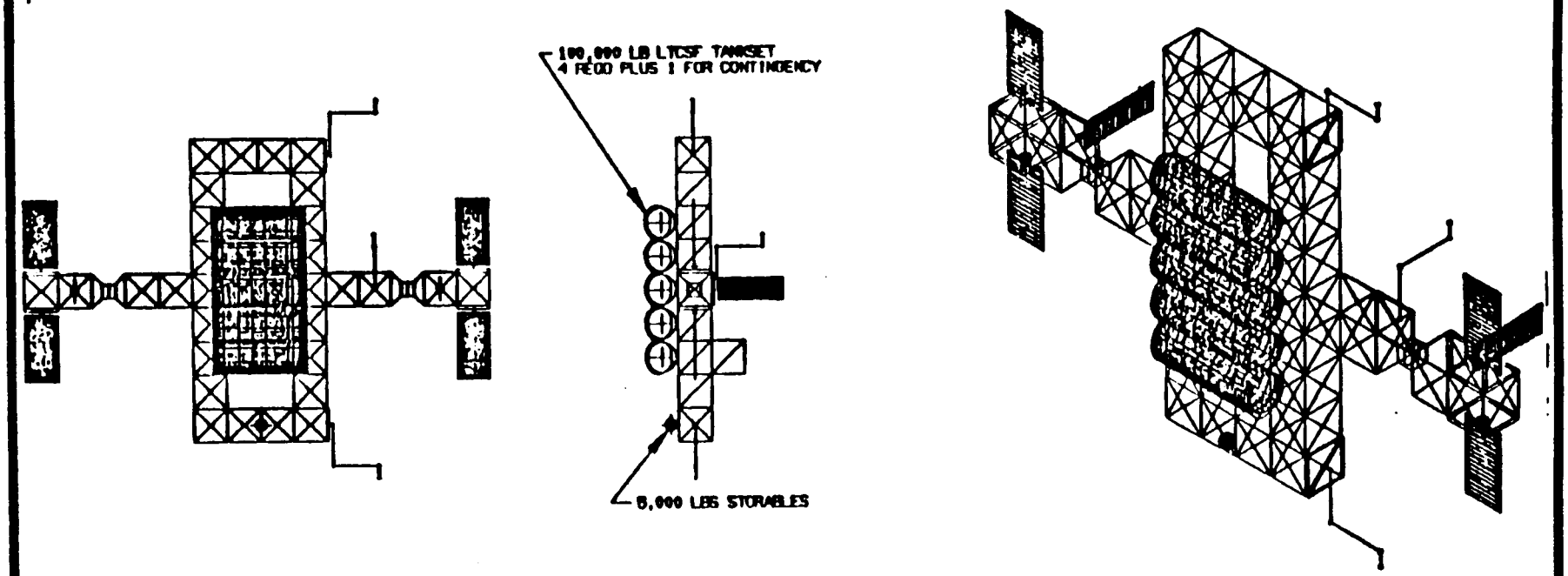
LUNAR OBSERVATORIES PROPELLANT PROVISIONING; CO-ORBITING PLATFORM



ORBITAL DEPOT FOR LUNAR OBSERVATORIES

FILENAME: 836.WHY.OFP-LUNOBS

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"HOOK AND SCAR" ISSUES

Identifying hard "hook and scar" requirements and providing actual space station design changes for them was beyond the scope of this effort. However, the effort highlighted some areas that should be considered for design enhancements to enable future capabilities in on-orbit fluid management. These included implications for both hardware and software. The chart summarizes these areas.

"HOOKS AND SCARS"

SPACE STATION DESIGN MUST CONSIDER SCARRING FOR:

- TRUSS STRUCTURE BEAM STRENGTHENING FOR LARGE ATTACHED PROPELLANT TANKS
- DUAL MOBILE REMOTE MANIPULATOR SYSTEMS (MRMS'S)
- SPACE ALLOCATION FOR PROPELLANT TANKS
- LOGISTICS CARRIER INTERFACES MUST BE COMPATIBLE WITH GROWTH SPACE STATION NEEDS
- ATTITUDE CONTROL SYSTEM MUST BE CAPABLE OF GROWTH TO ACCOMMODATE INCREASED MASS OF SPACE STATION WITH ATTACHED PROPELLANT TANKS

SPACE STATION DESIGN MUST CONSIDER SOFTWARE "HOOKS" FOR:

- OPERATION AND COORDINATION OF TWO MRMS'S
- PROVISION FOR INTEGRATED NITROGEN SYSTEM (INS) GROWTH

HARDWARE DEVELOPMENT REQUIRED FOR SPACE STATION BASED PROPELLANT PROVISIONING

There are several technologies that are required for the realization of cryogenic and storable fluid storage, acquisition, and transfer in the LEO environment. Some of these are:

- Cryogenic and storable fluid disconnects which may be mated by telerobotic operations will be necessary to minimize EVA for fluid carrier delivery and transfer operations.

- Space-qualified refrigeration systems will be needed for propellant storage at the SS, if no venting of oxygen or hydrogen boiloff is allowed, a refrigeration system must be used to condense all boiloff, and return the propellants to storage temperature and pressure.

- Cryogenic valves, pumps, compressors, and capillary liquid acquisition devices for the control of all storage and transfer functions within a propellant storage tankset are not all presently available. Low flow rate Joule-Thompson valves, check valves, low head/flow rate pumps, and high pressure gas compressors designed for low maintenance applications will be needed.

- Mobile remote manipulator system (MRMS) and orbital maneuvering vehicle (OMV) enhancements will need to be developed.

The instrumentation requirements for propellant and other fluid storage tank monitoring and process control are unique due to the lack of substantial gravity. Two-phase flow, mass gauging, and leak detection for microgravity, low pressure environments are not readily available.

HARDWARE DEVELOPMENT REQUIRED FOR SPACE STATION BASED PROPELLANT PROVISIONING

HARDWARE

- CRYOGENIC FLUID DISCONNECTS
- SPACE-QUALIFIED CRYOGENIC REFRIGERATION SYSTEM(S)
- LONG-LIFE SPACE QUALIFIED CRYOGENIC VALVES, PUMPS, COMPRESSORS
- MRMS CAPABLE OF HANDLING "LARGE" MASSES (I.E., PROPELLANT TANKAGE)
- GROWTH OMV OR ACEM EQUIVALENT
- MICROGRAVITY LIQUID ACQUISITION SYSTEM

INSTRUMENTATION

- MICRO-G MASS GAUGING
- MICRO-G TWO-PHASE FLOW INSTRUMENTATION
- LEAK DETECTION TECHNOLOGY FOR MICRO-G, LOW PRESSURE ENVIRONMENT

CONCLUSIONS AND RECOMMENDATIONS

There are a variety of fluid users which require a variety of fluids and use rates. The storage methods must accommodate fluids ranging from a high pressure gas or supercritical state fluid to a subcooled liquid (and superfluid helium). The cryogenic propellant amounts required for NASA's STV, Planetary, and Code Z missions are enormous in comparison to the other fluid requirements.

In providing the SS attached experiments with required fluids, preliminary comparisons have shown that the best method utilized hard fluid lines between each user and a manifold/ disconnect panel to which each fluid carrier is docked. This capability, however, is not needed at the initial SS (which provides the wide range of fluid use rates/users with fluids via ORU changeout, and bulk LHe replenishing in the case of ASTROMAG) and should only be used for the growth SS if operational and economic benefits are shown to exist.

Reboost settling is not recommended as a baseline mode of operation. Reboost operations of the SS could be scheduled to provide acceleration levels required for "settled" transfer of LH2/LO2 from the SS to an STV propellant tank. However, there are many other issues that need resolution to allow STV propellant provisioning from the SS, such as SS truss structure dynamics, safety, guidance, navigation, and control issues.

The Station must have two Mobile Remote Manipulator Systems (MRMS) and the ACEM for propellant handling operations for the STV at the SS. The two MRMSs must have accommodations for holding full and empty experiment fluid reservoir tanks/bottles, which will also require associated software capabilities.

Propellant needs for the manned planetary Code Z mission models will most likely be provided by co-orbiting propellant platform(s). Although reducing some of the direct impacts to the space station, the station will still have to provide crew accommodations during platform build-up, a shuttle vehicle, and will direct platform operations.

CONCLUSIONS AND RECOMMENDATIONS

- WIDE VARIETY OF FLUIDS USERS, VARIETY OF FLUIDS AND USE RATES
  - MUST ACCOMMODATE FLUIDS RANGING FROM HIGH PRESSURE GASES TO SUBCOOLED LIQUIDS (E.G., SUPERFLUID HELIUM)
  - HYDRAZINE AND LIQUID HELIUM CONSTITUTE MAJOR PORTION OF ATTACHED AND FREE-FLYING PAYLOAD FLUID REQUIREMENTS
  - LARGE AMOUNTS OF CRYOGENIC HYDROGEN AND OXYGEN PROPELLANTS
- SUGGESTED AN INTEGRATED FLUID SUBSYSTEM ARCHITECTURE FOR PROVISIONING ATTACHED AND FREE-FLYING PAYLOADS
- RECOMMEND TWO MOBILE REMOTE MANIPULATOR SYSTEMS (MRMS)
- ATTITUDE CONTROL ENHANCEMENT MODULE (ACEM) RECOMMENDED TO ENHANCE ORBITAL MANEUVERING VEHICLE (OMV) CAPABILITY
- CREW TRANSPORT VEHICLE (MAN-RATED OMV) FOR TRANSPORT BETWEEN SPACE STATION AND CO-ORBITING PROPELLANT DEPOT